

Thermal Properties of Hydrocarbons under Pressure

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Thermal Properties of Hydrocarbons under Pressure

I. Pentane and a Paraffinic Naphtha

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A KNOWLEDGE of the thermal properties of hydrocarbons at elevated temperatures and pressures is essential in present petroleum engineering work, particularly in the design of cracking stills, high-pressure heat exchangers, fractionating columns, and flash vaporizers.

Considerable work has been reported on the specific heats at atmospheric pressure of petroleum liquids and vapors (1, 2, 5, 7, 10, 13), but little work has been done on the experimental determination of the enthalpy ($H = U + PV$), popularly known as total heat, particularly as affected by pressure. Weir and Eaton (17) have studied the thermal properties of liquids and vapors and the change in enthalpy with pressure of a vaporized naphtha. Gary, Rubin, and Ward (8) determined the heat content of petroleum fractions as a function of temperature and pressure.

This paper reports experimental determination of the enthalpy and Joule-Thomson coefficients of the vapors of pentane and of a painter's naphtha.

EXPERIMENTAL PROCEDURE

APPARATUS. The apparatus used in this work operates on the continuous-flow principle and includes a throttling calorimeter for determining the Joule-Thomson effect and a calorimeter condenser for determining the enthalpy of the material referred to the cold liquid.

A flow diagram of the apparatus is given in Figure 1.

The parts as numbered are: 1, storage tank; 2, pressure pump; 3, mercury-sealed surge chamber; 4, pressure relief valve; 5, heating coil; 6, entrainment separator; 7, multiple-plate throttling calorimeter; 8, back-pressure valve; 9, inlet-pressure gage; 10, outlet-pressure gage; 11, calorimeter condenser; 12, oil three-way valve; 13, water three-way valve; 14, 17, 18, 19, coolers; 15, oil-circulating

Experimental data are reported on the Joule-Thomson coefficient and total heat or enthalpy at high pressures of pentane and of a painter's naphtha. The Joule-Thomson effect may be computed from published equations in the case of pure compounds, but relatively large errors may be made if mixtures are assumed equivalent to pure compounds. Because the effect of pressure on enthalpy is much less than the effect of temperature, mixtures may be assumed to be equivalent to pure substances for convenience and with satisfactory results for most present engineering requirements, but the effect of pressure may not be neglected.

pump; 16, air-stripping column with heater leg 22 and reflux condenser 21; 20, step-down transformer for heating coil 5.

Most of the equipment, including the pressure pump, was made in the university shops. The pressure gages are calibrated within one pound per square inch. The thermocouples are calibrated and read within 1° F., and both calorimeters have direct-reading thermocouples on their inlets and outlets and also differential thermocouples.

The throttling calorimeter is designed along the ideas developed by Callendar (3) during his researches on the thermal

properties of steam. The vapor-jacketed thermocouple wells are of different design from those used by Callendar. The mechanical details of the throttle may best be given by Figure 2. The throttle is incased in a magnesia block 6 inches square and 12 inches long. The heat losses between the two thermocouples are negligible because experimental tests, under the same conditions of temperature and pressure, give the same temperature drop across the orifice, owing to the expansion, whether a large amount or a small amount of the material is passed through the throttle per unit time.

The calorimeter condenser is also of similar design to that used by Callendar (3). The concentric copper tubes are brazed together with proper headers to give an outer water shield, an air jacket, a water jacket, a vapor condensing space, and a center water tube. The details of construction and of material flow are given in Figure 3. The experience gained during this investigation indicates that a helical tubular condenser with a water shield might be preferable for use with hydrocarbons.

The flow of the material is maintained constant for 15 minutes before taking samples in order to obtain steady conditions of temperature and pressure throughout the apparatus. In taking readings, valves 12

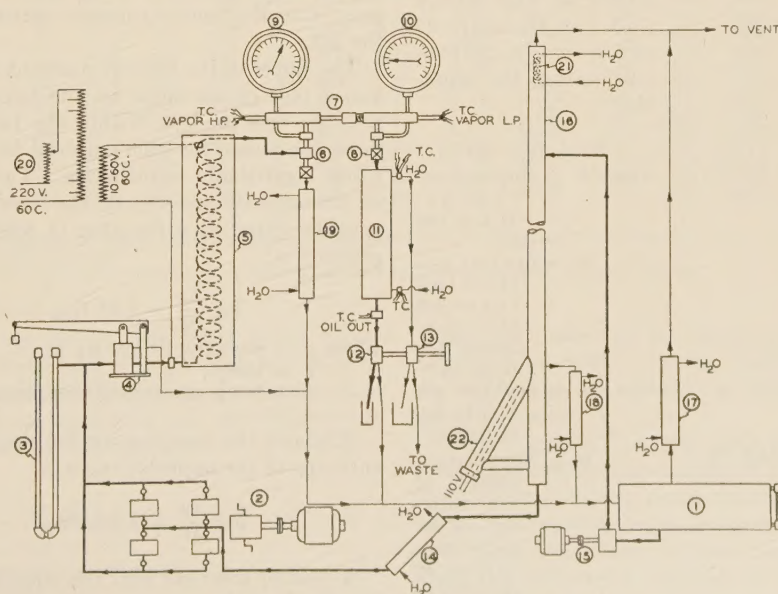


FIGURE 1. FLOW SHEET OF APPARATUS

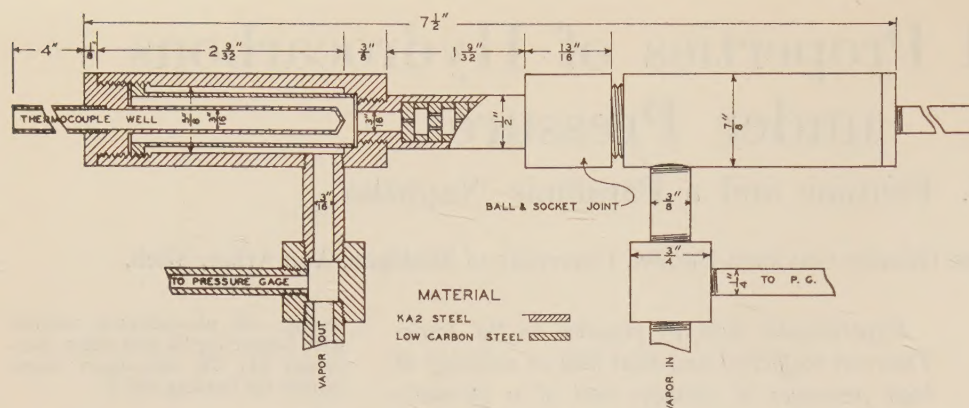


FIGURE 2. THROTTLING CALORIMETER

and 13 in Figure 1 are turned to allow oil and water to flow into the respective receivers until sufficient samples are obtained. All tests were conducted under an atmospheric pressure of 14 pounds per square inch.

MATERIALS. The two materials studied so far are paraffinic in chemical nature, but one is a substantially pure hydrocarbon and the other a complex mixture. The pentane, supplied by the Phillips Petroleum Company, analyzed 94 per cent *n*-pentane and 6 per cent isopentane with a Podbielniak column (14). The naphtha, supplied by the Old Dutch Refining Company, is their Varnish Maker's and Painter's naphtha. The distillation curves of this naphtha are given in Figure 4.

RESULTS. The averaged data for each run are given in Tables I and II. Although many operating and apparatus difficulties were encountered in the original apparatus, the results obtained are accurate probably within about ± 5 per cent.

The radiation losses from the apparatus must be the same per unit time for the same temperature of material and can be calculated by simultaneous equations when the initial temperatures and pressures is the same and the flow of oil per hour is different, using the equation:

$$\bar{h}x + L = \bar{H}x$$

where $\bar{h}$ = observed enthalpy, B.t.u. per lb.

x = material flowing through the condenser per hour, lb.

L = heat loss per hour by radiation

$\bar{H}$ = corrected enthalpy of the material at the given condition as referred to the cold liquid

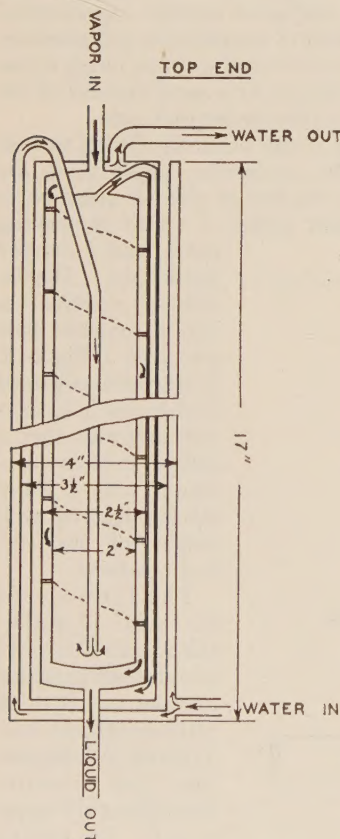


FIGURE 3. CALORIMETER CONDENSER

The enthalpy of the vapor was calculated for each run. A plot of the relative enthalpy at atmospheric pressure so determined, as a function of temperature (Figure 5), indicates that the equation for the specific heat of vapor given by Cope, Lewis, and Weber (4) is the most satisfactory of those published for pentane and for naphtha when applied by means of the equivalent pure compound by the Ragatz method (15):

$$MC_p = 1.826 + 1.587n + 1.267m + (-0.0027 + 0.0048n + 0.00197m)t \quad (1)$$

where MC_p = molal specific heat, B. t. u. per $^{\circ}$ F.

n = number of carbon atoms

m = number of hydrogen atoms

t = temperature, $^{\circ}$ F.

The data for each material were plotted with temperature and pressure coordinates such as Figure 7. From these plots it was found that, within the experimental error, the lines of

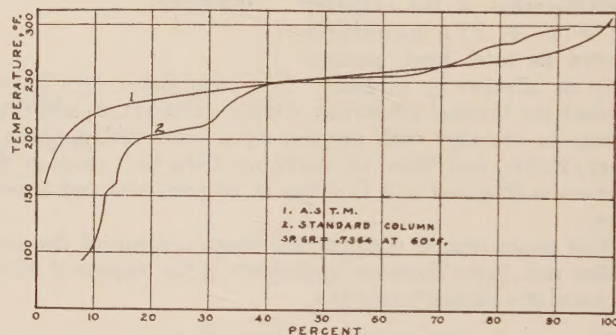


FIGURE 4. DISTILLATION ANALYSES OF NAPHTHA

constant enthalpy are straight over the range covered. At higher temperatures it is expected, from analogy with other gases, that the lines of constant enthalpy will curve upward to the left.

The slopes of the lines of constant enthalpy were calculated and a plot of the slope *vs.* the temperature at atmospheric pressure was made. Within the limits of the experimental data, the points for each material fall on a straight line when using logarithmic coordinates. The equation for the slope at atmospheric pressure of the lines of constant enthalpy of pentane vapor as a function of temperature at atmospheric pressure is:

$$\log \frac{\Delta p}{\Delta t} = 1.45 (\log t_0 - 1.945) \quad (2)$$

where p = pressure, lb. per sq. in.

t = temp., $^{\circ}$ F.

t_0 = temp. at atmospheric pressure, $^{\circ}$ F.

Similarly the equation for the slope of the lines of constant enthalpy of the naphtha vapor is:

$$\log \frac{\Delta p}{\Delta t} = 2.328 (\log t_1 - 2.392) \quad (3)$$

A plot of the data and the equations is given in Figure 6. The final results are plotted as lines of constant enthalpy in Figures 7 and 8.

TABLE I. EXPERIMENTAL DATA ON PENTANE

TEST	TEMPERATURE						THROTTLE VAPOR			WEIGHT			DURATION OF TEST	HEAT QUANTITIES ^a				ENTHALPY ^b	
	THROTTLE IN- let	VAPOR OUT- let	CON- DEN- SATE	CON- DEN- SER	WATER RISE	VAPOR AT 1 ATM.	IN- LET	OUT- LET	DROP	VAPOR TEST	PER hr.	CON- DEN- SER		$\overline{h}_t$	$\overline{h}_a$	$\overline{h}_r$	$\overline{h}_c$	$\overline{H}_h$	$\overline{H}$
	° F.	° F.	° F.	° F.	° F.	° F.	Pounds per sq. in.			Lb.	Lb.	Lb.							
1	266	245	21	70	33.5	245	114	14	100	2.48	5.29	17.23	28	577	1237	22	196	1455	275
2	338	307	31	74	29	307	214	16	198	2.74	10.96	27.07	15	785	3140	31	427	3598	328
3	372	331	41	74	18	331	316	19	297	3.40	17.00	56.05	12	1009	5045	35	663	5743	338
4	264	243	21	63	21.5	243	116	15	101	2.57	7.71	30.9	20	664	1992	22	254	2268	294
5	202	187	15	66	27.5	187	65	15	50	2.03	6.09	16.0	20	440	1320	14	213	1547	254
6	266	252	14	68	30.5	242	114	59	55	2.45	7.35	17.9	20	546	1683	22	265	1970	268
7	418	343	75	68	28	343	516	15	501	2.92	8.35	31.2	21	874	2498	40	301	2839	340
8	449	391	58	70	30.5	391	517	15	502	2.62	7.87	28.3	20	863	2589	44	291	2924	371
9	553	517	36	67	27.5	517	513	15	498	2.26	6.78	32.2	20	886	2658	56	241	2955	436
10	650	619	31	70	31.5	619	511	15	496	2.19	6.51	32.1	20	1011	3033	68	241	3342	514
11	763	739	24	67	26	739	509	15	494	2.08	6.24	42.9	20	1115	3345	81	222	3648	585
12	557	485	72	67	28	485	936	17	919	2.24	6.72	30.4	20	851	2553	56	239	2848	424
13	733	688	45	70	33	688	946	17	929	2.05	6.15	32.0	20	1056	3168	78	228	3474	565
14	883	863	20	71	36.5	863	595	17	578	2.55	7.65	46.5	20	1697	5091	95	287	5473	715

^a h_t = heat transferred to condenser water during test; h_a = heat transferred to condenser water per hour; h_r = heat radiated per hour from throttle and condenser; h_c = sensible heat of condensate above 0° F., hourly basis.

^b H_a = enthalpy referred to 0° F. of vapor passing through throttle per hour; H = corrected enthalpy of pentane at inlet conditions, as referred to liquid at 0° F. and 1 atmosphere.

TABLE II. EXPERIMENTAL DATA ON VARNISH MAKER'S AND PAINTER'S NAPHTHA

TEMPERATURE																			
RUN	THROTTLE VAPOR			CON- DEN- SER WATER, OUT CHANGE	CON- DEN- SER VAPOR AT 1 ATM.	THROTTLE VAPOR PRESSURE			WEIGHT			DURA- TION OF TEST	HEAT QUANTITIES ^a				ENTHALPY ^b		
	In- let ° F.	Out- let ° F.	Drop ° F.			In- let	Out- let	Drop	Vapor Test	Per hr.	Condenser Water		h _t	h _a	h _r	h _c	H _a	H	
						Pounds	per	sq. in.	Lb.	Lb.	Lb.		Min.	B. t. u.	B. t. u.	B. t. u.	B. t. u.	B. t. u./hr.	B. t. u./lb.
1	639	625	14	76	63.5	625	116	15	101	2.72	5.44	18.17	30	1154	2308	66	232	2606	479
2	627	617	10	76	65.0	606	115	65	50	1.80	3.60	16.96	30	1102	2204	65	158	2427	674
3	647	616	31	66	42.5	614	310	18	292	5.10	15.30	55.00	20	2338	7014	68	558	7640	500
4 ^c	258	248	Flashed	100	60.0	...	315	23	...	6.21	...	9.80	4	...	...	...	...	...	...
5	785	766	19	70	54.0	765	315	18	297	2.35	14.10	24.63	10	1330	7980	84	550	8614	610
6	732	714	18	69	51.0	704	316	114	202	2.98	11.18	38.90	16	1984	7440	77	430	7947	711
7	681	669	12	68	49.5	644	320	218	102	4.10	15.38	38.62	16	1912	7170	71	584	7825	509
8	707	697	10	69	38.5	633	727	652	75	4.09	13.63	50.75	18	1954	6513	75	525	7113	521
9	692	634	58	85	84.5	634	500	15	485	2.97	7.13	15.31	25	1294	3106	73	346	3525	495
10	689	654	35	76	60.5	644	517	118	399	1.92	7.20	14.39	16	871	3266	73	307	3646	506
11	658	613	45	76	61.0	581	518	216	302	2.45	7.35	17.20	20	1049	3147	69	313	3529	480
12 ^c	153	151	Liquid	93.5	59.0	...	518	17	...	6.20	...	3.46	11	...	...	...	...	...	...
13 ^c	149	145	Liquid	94.5	60.0	...	315	16	...	6.20	...	3.42	15	...	...	...	...	...	...
14	708	613	95	73	53.5	612	832	19	813	4.30	12.90	36.45	20	1950	5850	75	529	6454	500
15 ^c	402	270	Flashed	74	56.5	...	561	19	...	5.84	...	20.80	15	...	...	...	...	...	...
16 ^c	292	237	Flashed	72	44.0	...	483	16	...	5.81	...	17.43	15	...	...	...	...	...	...
17 ^c	203	203	Liquid	76.5	46.5	...	447	15	...	4.60	...	8.28	9	...	...	...	...	...	...
18 ^c	202	202	Liquid	74	42.0	...	446	15	...	5.87	...	14.77	15	...	...	...	...	...	...
19 ^c	124	126	Liquid	69	30.0	...	419	15	...	5.72	...	6.43	15	...	...	...	...	...	...
20	707	657	50	63	33.5	656	520	16	504	1.45	5.80	21.92	15	734	2936	75	203	3214	554
21	715	654	61	77	67.0	653	521	16	505	1.60	4.36	10.36	22	694	1893	75	189	2157	495
22	709	668	41	69	51.5	657	512	114	398	3.42	12.83	32.50	16	1674	6278	75	494	6847	533
23	708	684	24	70	51.5	646	521	321	200	3.10	12.40	29.72	15	1531	6124	75	484	6683	539
24	704	655	49	73	58.0	654	514	16	498	3.68	11.04	29.24	20	1696	5088	74	453	5615	509
25	607	564	43	67	38.0	564	365	16	349	3.38	8.11	36.54	25	1389	3334	63	302	3699	456
26	751	701	50	68	43.0	700	614	17	597	3.03	12.97	34.88	14	1500	6420	80	493	6993	539
27	799	733	66	74	54.5	731	1014	23	991	3.40	22.66	32.35	9	1763	11,752	86	940	12,778	563
28	706	656	50	69	49.0	654	513	22	491	4.06	22.13	40.15	11	1967	10,720	75	852	11,647	526
29	557	521	36	64	32.0	520	265	16	249	3.31	11.68	41.92	17	1341	4734	57	414	5305	454
30	499	471	28	75	56.0	470	164	14	150	2.20	7.33	13.72	18	768	2560	50	308	2918	398
31	470	448	22	73	45.0	448	114	14	100	1.63	4.89	12.21	20	549	1647	46	201	1894	387
32	500	476	24	70	49.0	475	164	17	147	3.56	14.24	25.55	15	1252	5008	50	555	5613	394
33	401	387	14	74	45.5	387	64	15	49	1.84	5.52	12.61	20	574	1722	38	229	1989	360
34 ^d	609	513	96	81	67.0	513	529	16	513	3.32	9.96	18.21	20	1220	3660	62	448	4170	419
35	717	664	53	87	83.0	664	547	16	531	2.94	8.82	15.80	20	1311	3966	76	441	4483	508
36	784	745	39	73	42.0	744	546	16	530	2.72	8.16	33.41	20	1403	4209	84	335	4628	567
37	664	600	64	79	55.0	600	529	16	513	2.74	8.22	20.81	20	1145	3435	70	370	3875	472
38	246	232	14	65	17.0	232	514	14	500	2.07	41.4	13.44	30	228	4570	20	153	628	152
39	256	240	16	67	17.0	240	474	16	458	5.88	29.40	41.80	12	710	3553	21	1088	4662	159
40	795	751	44	79	52.0	751	521	16	585	2.07	6.21	12.11	20	1098	3294	85	279	3658	589
41	659	600	59	80	46.0	600	519	16	503	2.23	6.69	20.79	20	956	2868	69	301	3238	484
42	662	604	58	85	68.0	602	514	26	488	4.45	26.70	28.12	10	1912	11,472	69	1308	12,849	481
43	794	760	34	81	60.0	759	514	25	489	4.08	24.48	36.73	10	2204	13,224	85	1102	14,411	588
44	430	420	10	79	53.0	420	49	14	35	3.79	7.58	22.31	30	1182	2364	42	341	2747	363
45	449	440	9	76	43.5	440	49	14	35	3.65	7.30	28.33	30	1232	2464	44	314	2822	386

^a Symbols same as in Table I.

^b H = corrected enthalpy of naphtha at inlet conditions as referred to liquid at 0° F. and 1 atmosphere pressure.

^c Liquid present, not used in calculations.

^d Runs 34 to 45, inclusive, were made after insulation on apparatus was improved to decrease radiation losses.

The data for the pentane can be considered as for *n*-pentane because the small percentage of isopentane will have no appreciable effect since their P-V-T relations are very similar.

Lewis and Luke (11) have suggested that the difference in enthalpy may be computed by the equation:

$$H_1 - H_0 = -(S - 1)FRT(1 - Z) - RT(1 - Z) \quad (4)$$

where S , F = empirical constants

Z = ideal gas law correction factor for volume at the high pressure

R = gas constant

T = abs. temp.

Values calculated by this equation agree fairly well with the experimental results over the range covered for pentane, when H_0 is taken as the enthalpy at atmospheric pressure, as indicated in Table III.

Watson and Nelson (16) have published a chart for calculating the isothermal change of enthalpy with pressure for hydrocarbon vapors, which eliminates the rather tedious calculations necessary when using the above equation. Values read from this chart indicated a greater effect of pressure upon the enthalpy of pentane by about 25 per cent than is found by experiment. This may be readily explained as due to the simplifying assumptions made in preparing the chart.

PETROLEUM FRACTIONS

Ragatz (15) has recently proposed the hypothesis that the line of the dew points of a naphtha when plotted on a vapor pressure chart intersects the line through the critical points of pure hydrocarbons of the same gravities and molecular weights, at a point which is the critical temperature and pressure of the pure hydrocarbon having thermal properties at atmospheric pressures equivalent to those of the naphtha.

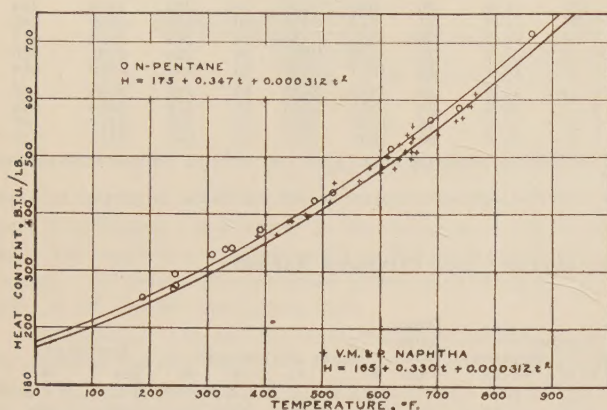


FIGURE 5. ENTHALPY OF VAPOR AT ATMOSPHERIC PRESSURE

The dew point curve for the naphtha herein studied was calculated by the method of Katz and Brown (9) and found to intersect the line through the critical points of the normal paraffin hydrocarbons at a point corresponding to a hypothetical compound $C_{7.5}H_{17}$ with critical point at 542° F. and 380 pounds per square inch absolute. The experimental data obtained on naphtha in this investigation is further evidence in support of Ragatz's hypothesis but indicates that this hypothesis is of little or no use in determining the thermal properties of petroleum vapors at high pressures, as no better results at high pressure are obtained than from the simpler assumption that the critical temperature of the naphtha is the same as the critical temperature of the equivalent normal paraffin hydrocarbon.

TABLE III. COMPARISON OF EXPERIMENTAL WITH COMPUTED JOULE-THOMSON EFFECTS ON *n*-PENTANE

HEAT CONTENT ABOVE 0° F. B. t. u./lb.	PRESSURE Lb./sq. in.	TEMPERATURE		
		EXPERIMENTAL ° F.	COMPUTED Watson (16) ° F.	Lewis (11) ° F.
400	14.7	460	460	460
	500	506	520	508
	1000	555	555	557
500	14.7	606	606	606
	500	635	648	638
	1000	666	682	663
600	14.7	737	737	...
	500	759	768	...
	1000	782	796	...

The critical temperature equation of McKee and Parker (12) is:

$$t_c = 1.05t_b + 286$$

where t_b = the arithmetic average of the initial and every 10 per cent cut temperature

This gives a critical temperature of 549° F. for the naphtha, which is the apparent critical temperature of a hypothetical normal paraffin of $C_{7.7}H_{17.4}$. Eaton and Porter's equation (6) based on the A. S. T. M. 50 per cent point and gravity gives a critical temperature of 577° F., corresponding to an equivalent normal paraffin hydrocarbon $C_{8.3}H_{18.6}$. When using the method for determining the critical temperature as proposed by Watson and Nelson (16), the equivalent hydrocarbon is C_8H_{18} .

If the enthalpy of the naphtha is considered to be the same

as that of the compound $C_{7.5}H_{17}$, Lewis and Luke's equation applied to $C_{7.5}H_{17}$ should give values in good agreement with experimental data according to Ragatz. This was found to be the case at atmospheric pressure, but the computed Joule-Thomson effect or change in temperature with pressure at constant enthalpy is 12 to 15 per cent less than the experimental results as indicated in Table IV.

TABLE IV. COMPARISON OF EXPERIMENTAL WITH COMPUTED JOULE-THOMSON EFFECTS ON A PARAFFINIC VARNISH MAKER'S AND PAINTER'S NAPHTHA

HEAT CONTENT ABOVE 0° F. B. t. u./lb.	PRESSURE Lb./sq. in.	TEMPERATURE			
		EXPTL. ° F.	Watson ^a (16) ° F.	Watson ^b (16) ° F.	Lewis ^a (11) ° F.
400	14.7	487	487	487	...
	500	585	562	562	...
	1000	...	583	583	...
500	14.7	638	638	638	638
	500	688	689	692	680
	1000	743	716	717	727
600	14.7	765	765	765	765
	500	800	805	810	796
	1000	836	835	835	828
700	14.7	883	883	883	...
	500	907	912	916	...
	1000	933	942	942	...

^a Equivalent hydrocarbon $C_{7.5}H_{17}$ by Ragatz dew point intersection (15).

^b Using reduced equations of state based on pure hydrocarbons as applicable directly to mixtures.

If Watson and Nelson's chart (16) is used to compute the effect of pressure for the naphtha, values from 8 per cent high to about 25 per cent low below 750° F. and about 20 per cent high at 950° F. with approximately correct results at intermediate temperatures are obtained when using either $C_{7.5}H_{17}$ or C_8H_{18} as the equivalent pure compound or the calculated critical temperature and pressure of the mixture itself as indicated in Table IV.

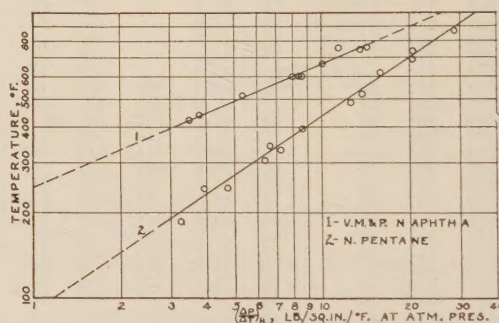


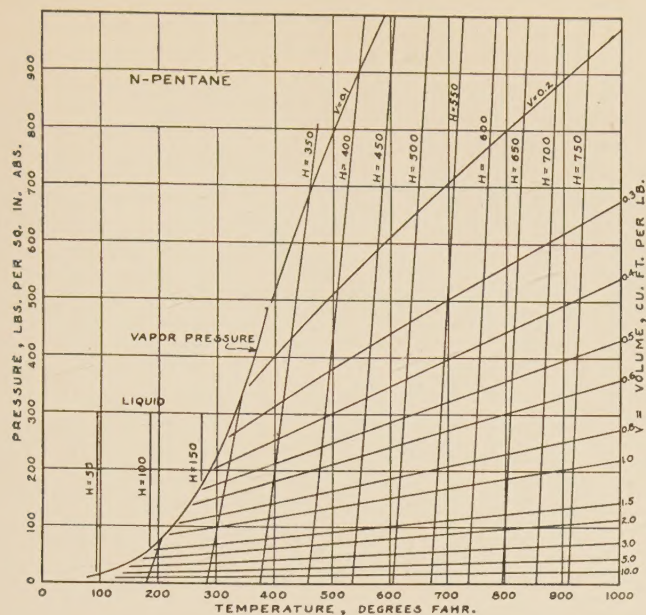
FIGURE 6. JOULE-THOMSON EFFECT

The experimental results of Weir and Eaton (17) on the enthalpy of the vapors of a 58° A. P. I. naphtha indicate a similar discrepancy in the calculated results as indicated in Table V. The reported experimental critical temperature (17) of 590° F., and an estimated (9) critical pressure of 350 pounds per square inch were used in conjunction with the Watson chart (16).

TABLE V. COMPARISON OF EXPERIMENTAL AND COMPUTED VALUES FOR JOULE-THOMSON EFFECT ON WEIR AND EATON'S 58° NAPHTHA C (17)

HEAT CONTENT ABOVE 0° F. B. t. u./lb.	PRESSURE Lb./sq. in.	TEMPERATURE	
		Exptl. ° F.	Calcd. ^a (16) ° F.
400	14.7	525	525
	500	618	605
	1000	650	622
500	14.7	688	688
	500	737	741
	1000	778	765
600	14.7	821	821
	500	868	868
	1000	892	892

^a Using reduced equations of state based on pure hydrocarbons and experimentally determined critical temperature 590° F. and critical pressure 350 pounds per square inch, and Watson and Nelson chart for corrections in enthalpy due to pressure.

FIGURE 7. CONSTANT-ENTHALPY LINES FOR *n*-PENTANE

CONCLUSIONS

Comparison of the data in Tables IV and V indicates that the calculated effect of pressure varies from the experimental data in the same way for the two different naphthas, indicating good agreement between the two sets of experimental data and a peculiar characteristic of the Watson chart caused by the simplifying assumptions used in its derivation. Attention should also be called to the fact that, although values computed by Equation 4 from Lewis and Luke (11) agree well with experimental data on a single component, pentane, values so computed indicate too small an effect of pressure in the case of mixtures such as naphtha.

Although there is no basis in the ideal solution laws for the assumption that a mixture would have the same thermal properties as a pure substance; the fact that the more volatile components at a greater T_r and less P_r have a smaller enthalpy change and the less volatile components at a smaller T_r and greater P_r have a greater enthalpy change led to the hope that these differences might compensate in a mixture to make a mixture equivalent to a single substance. But even if this may be true for any one temperature or pressure, the experimental results indicate that no such relationship exists over any appreciable range.

When precision may be sacrificed for convenience, a mixture may be treated approximately as a pure compound of the same critical temperature, pressure, and molecular weight as suggested by Watson (16). Although the results so obtained are by no means accurate, the correction due to pressure is so small compared with the effect of temperature on enthalpy that the final result so obtained is probably accurate enough for most engineering requirements at present. In any case it is far better thus to treat a mixture than to neglect entirely the effect of pressure upon enthalpy or heat content. As indicated, the actual effect of pressure on the enthalpy of mixtures is usually greater than is computed by this convenient assumption.

Equation 4 from Lewis and Luke (11) appears to give more reliable results on pure hydrocarbons over the range studied than the more convenient chart by Watson (16); but for mixtures considered as equivalent to pure hydrocarbons having the same critical temperatures and pressures, there is no advantage in using the equation. In general, Watson's chart (16) is convenient and appears adequate for most engineering

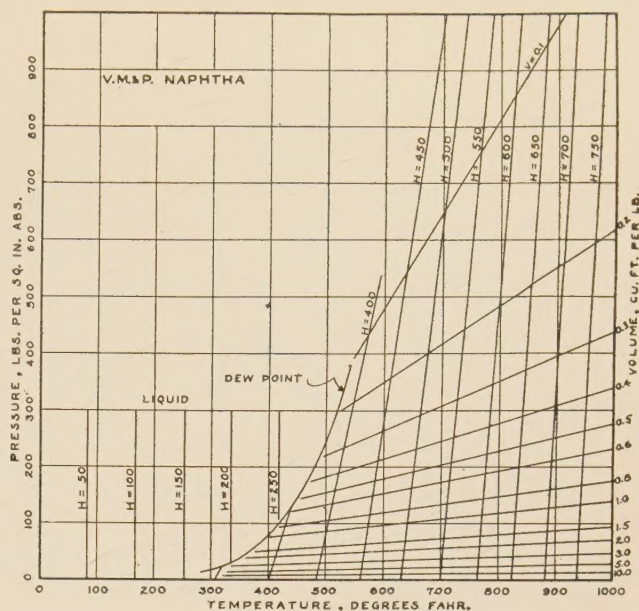


FIGURE 8. CONSTANT-ENTHALPY LINES FOR VARNISH MAKER'S AND PAINTER'S NAPHTHA

purposes although giving high results for pure compounds and low results in many cases for mixtures.

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